Rotary Transformer

Many spacecraft (S/C) and surface rovers require the transfer of signals and power across rotating interfaces. Science instruments, antennas and solar arrays are elements needing rotary power transfer for certain (S/C') configurations. Delivery of signal and power has mainly been done by using one of the simplest means, the s]ip ring, approach. This approach, although simple, leaves debris generating noise over a period of time. Another problem associated with slip ring is the frictional drag torque imposed on the system. Spacecraft and telecommunications satellite are requiring a life expectancy in excess of ten years. Now, (S/C) with higher data rates and poor slip ring life, are forced to interface with an alternate approach. The rotary transformer is a good alternative to slip rings for signal and power transfer. The rotary transformer has no appreciable drag torque and possesses a life expectancy, depending only upon the support bearings and the lubricating system, in excess of ten years with no debris. If power and weight is the main concern, with careful design, the rotary transformer can be used as the main inverter transformer.

Transformer Configuration

The rotary transformer is essentially the same as a conventional transformer except that the geometry is arranged so that the primary and secondary can be rotated with respect to each other with negligible changes in electrical characteristics. The power or signal transfer is accomplished electromagnetically across an air gap. A simple transformer with a primary and secondary is shown in figure 1. The standard transformer in figure 1 is to show the similarity to the basic rotary transformer. There are three possible basic configurations for the rotary transformer. They include the concentric cylinder or axial configuration shown in figure 2, face to face or pot core configuration shown in figure 3, and the LT core configuration shown in figure 4. The rotary transformer has a rotor core with primary winding and a stator core with the secondary winding separated by an air gap. The rotor is suspended on bearings much like a motor. This way the rotor is free to rotate in either direction.

Mechanical **Constraints**

The mechanical constraints on the rotary transformers has the biggest impact on the overall electrical design. Some of the mechanical constraints for the rotary transformer are:

1. The mechanical configuration (see figures 2-4).
2. The required size of the through bore.
3. The number of rotary transformers end to end.

4. The rotational sped of the rotary transformer.
5. The required gap for mechanical assembly.
6. The end of life in play.

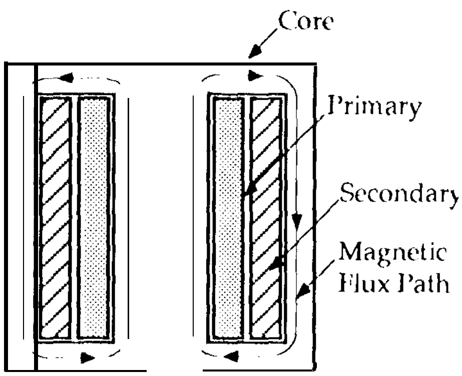


Figure 1. Standard Transformer

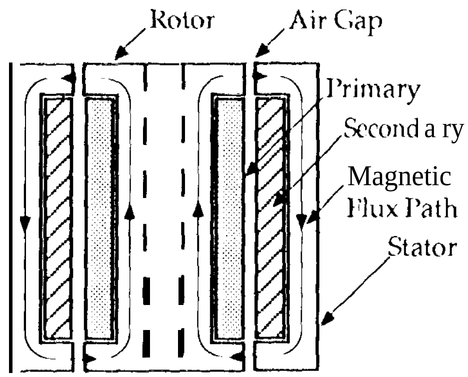


Figure 2. Axial Rotary Transformer

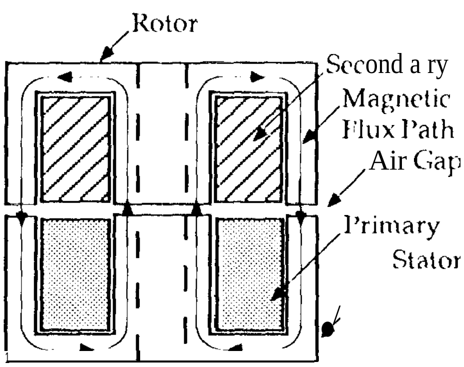


Figure 3. Pot Core Rotary Transformer

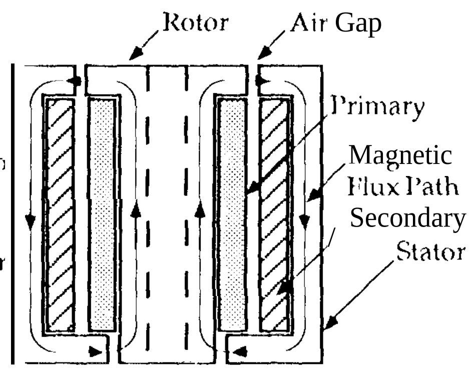


Figure 4. 1, or T Rotary Transformer

Transformer Design

The rotary transformer requirements posed some unusual design constraints, compared to the usual transformer design. First, the relatively large gap in the magnetic circuit results in a low primary magnetizing inductance. Secondly, the large space between primary and secondary windings results in an unusually high primary to secondary, leakage inductance. Thirdly, eddy currents, caused by fringing flux, can be formed in the magnetic material near the gap which could cause losses and local radiation. Finally, the large, throu~h-bore requirement results in an inefficient utilization of the core material and copper due to the fixed mean, length turn. The rotary is shown in figure 5.

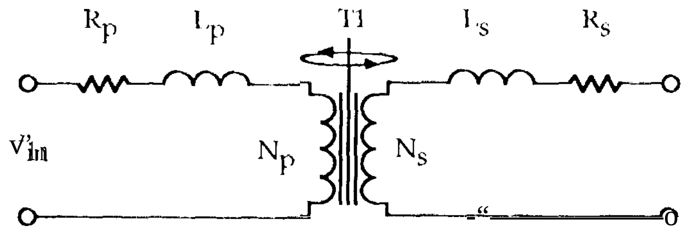


Figure 5. Rotary Transformer Schematic.

The design of a rotary transformer is the same as any other transformer. The turns are calculated using Faradays Law see equation (1):

$$N = \frac{V_{in}(10^{4})}{f B_m A_c K_f}, \quad \textit{\textbf{[turns]}} \ (1)$$

where:

Vin = applied voltage, volts

N = required number of turns

Bm = operating flux, tesla

f = frequency, hertz

Ac = area of the core, cm2

Kf = wave form factor, Kf = 4.0 square wave and 4.44 for a sine wave

In the normal transformer, the primary inductance is very high because there is little or no air gap. But, because of the air gap in the rotary transformer, the inductive component is very low. This inductive component can best be seen by the following inductance equation (2):

$$L = \frac{0.4\pi N^2 A_c (10^{-8})}{l_g + \frac{MPL}{\mu_m}}, \quad \text{[henrys]} \ (2)$$

where:

L = inductance, henrys

N = required number of turns

Ac = area of the core, cm2

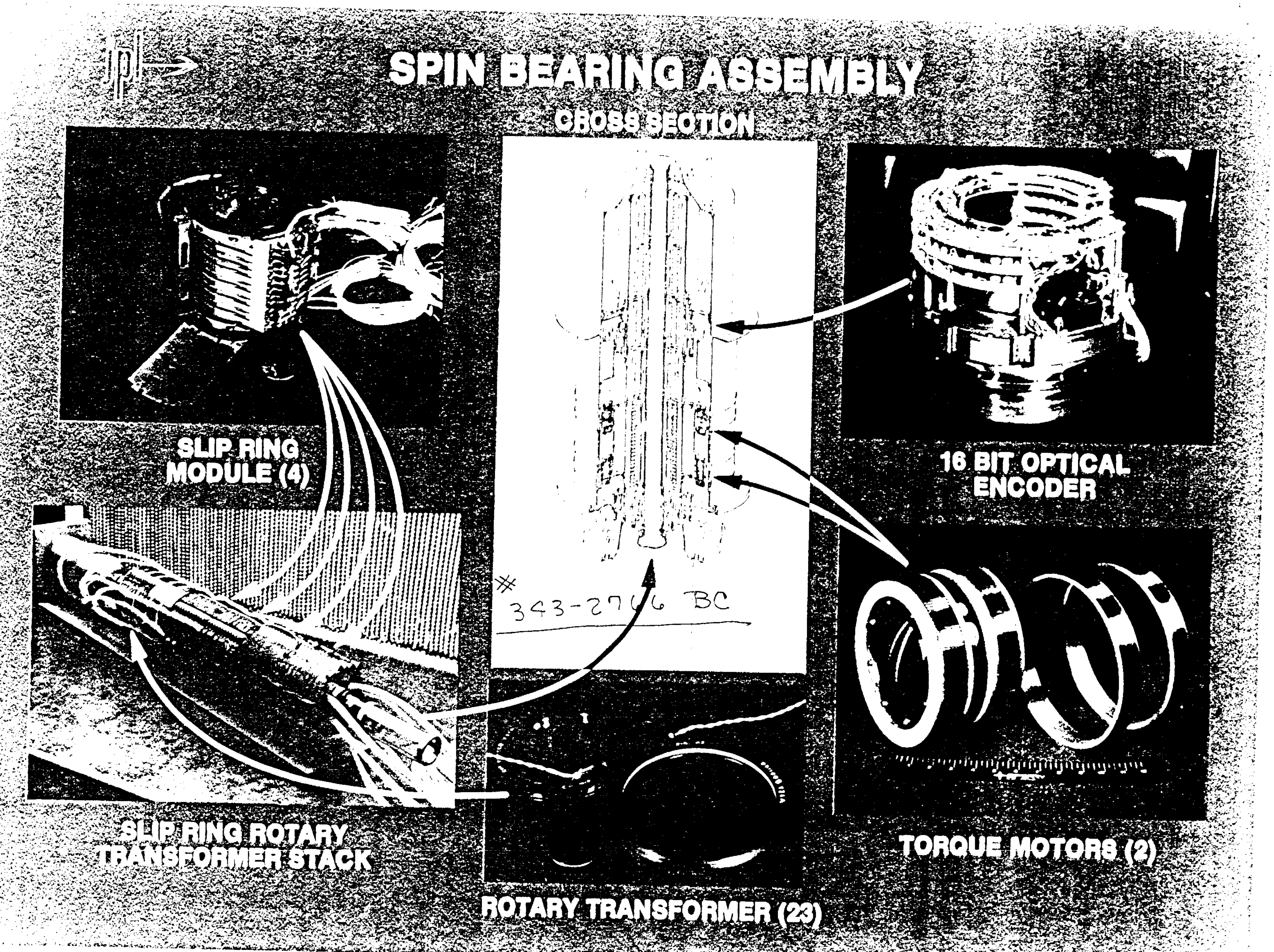
lg = gap length, cm

MPL = magnetic path length

μm = magnetic material permeability

conclusion

The rotary transformer can be designed to give good performance and long life for both signal and power. The Galileo spacecraft used a hybrid configuration on its spun and despun sections of the spacecraft. q'here are 24 rotary transformers on the Galileo spacecraft. This can be seen in the Spin Bearing Assembly (SBA) Figure 5.


jpl
SPIN BEARING ASSEMBLY
CROSS SECTION
SLIP RING MODULE (4)
16 BIT OPTICAL ENCODER
343-2766 BC
SLIP RING ROTARY TRANSFORMER STACK
TORQUE MOTORS (2)
ROTARY TRANSFORMER (23)